Reconstructing Primordial non-Gaussianity

Thomas Flöss (University of Groningen) - Sesto Workshop - 04/07/2024

Based on…

- 2206.10458 TF, Matteo Biagetti & Daan Meerburg
- 2305.07018 TF & Daan Meerburg
- 24xx.xxxxx Jelte Bottema, TF & Daan Meerburg

“How to optimally extract primordial non-Gaussianity from large-scale structure?”

What's wrong with the bispectrum?

- CMB is linear, LSS is highly non-linear
- Signal confusion (secondary non-Gaussianity)
- Mode coupling (non-Gaussian covariance)

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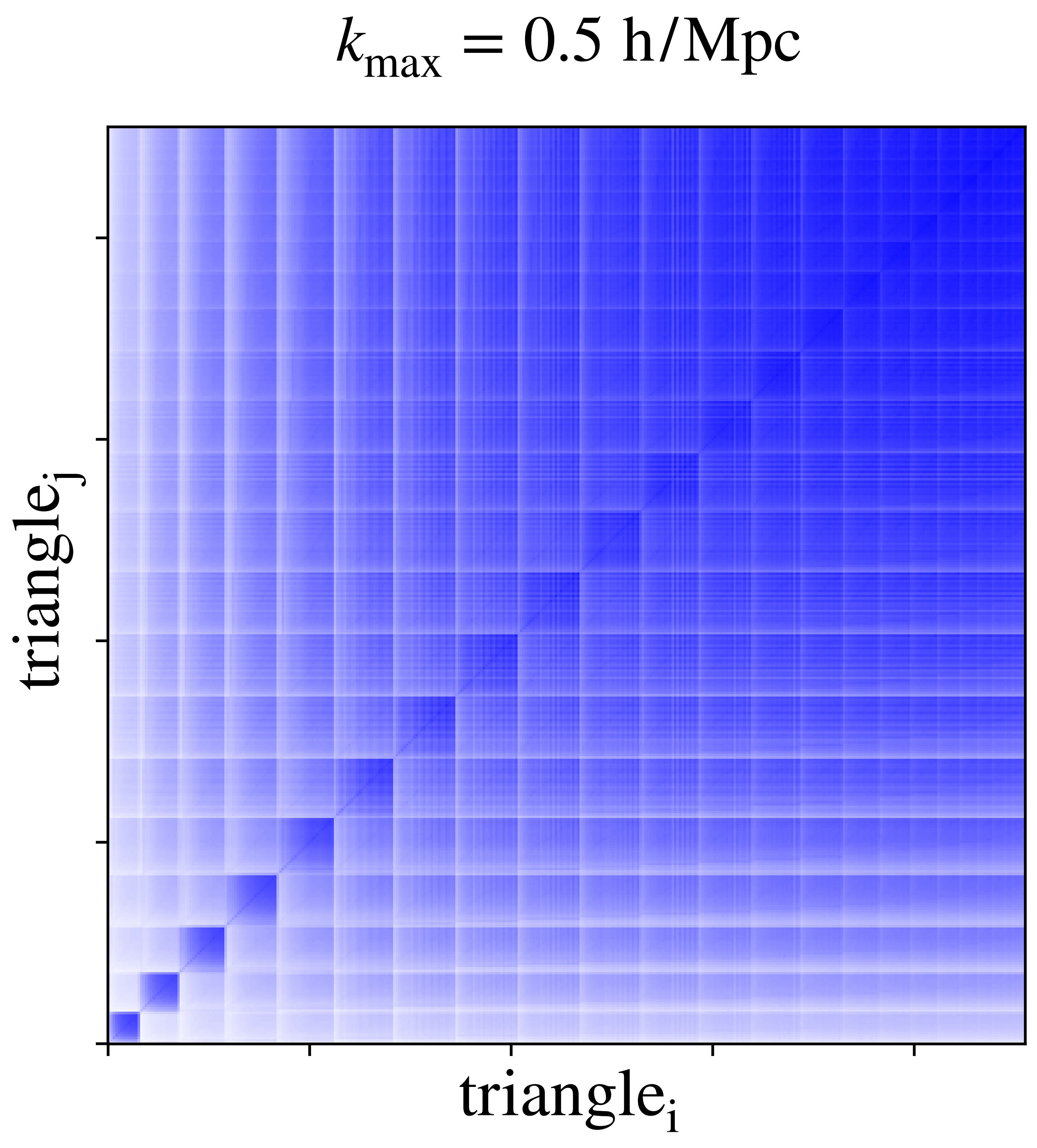


Figure: correlation matrix of non-linear matter bispectrum

What's wrong with the bispectrum?

- CMB is linear, LSS is highly non-linear
- Signal confusion (secondary non-Gaussianity)
- Mode coupling (non-Gaussian covariance)

- Constraints saturate
- Information moved to higher-order correlation functions

Biagetti++ 2021, Coulton++ 2022, Goldstein++ 2022, TF++ 2022

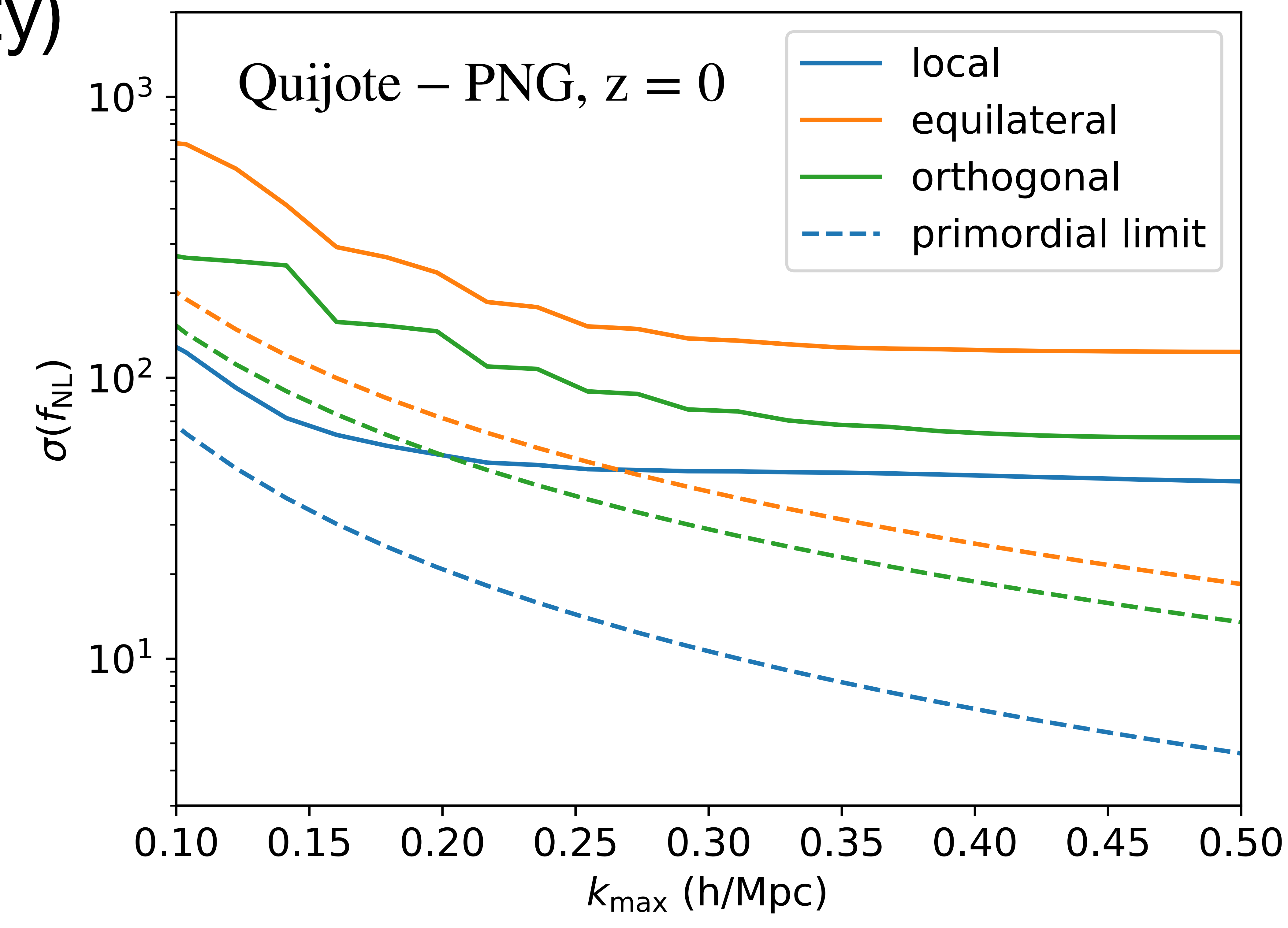


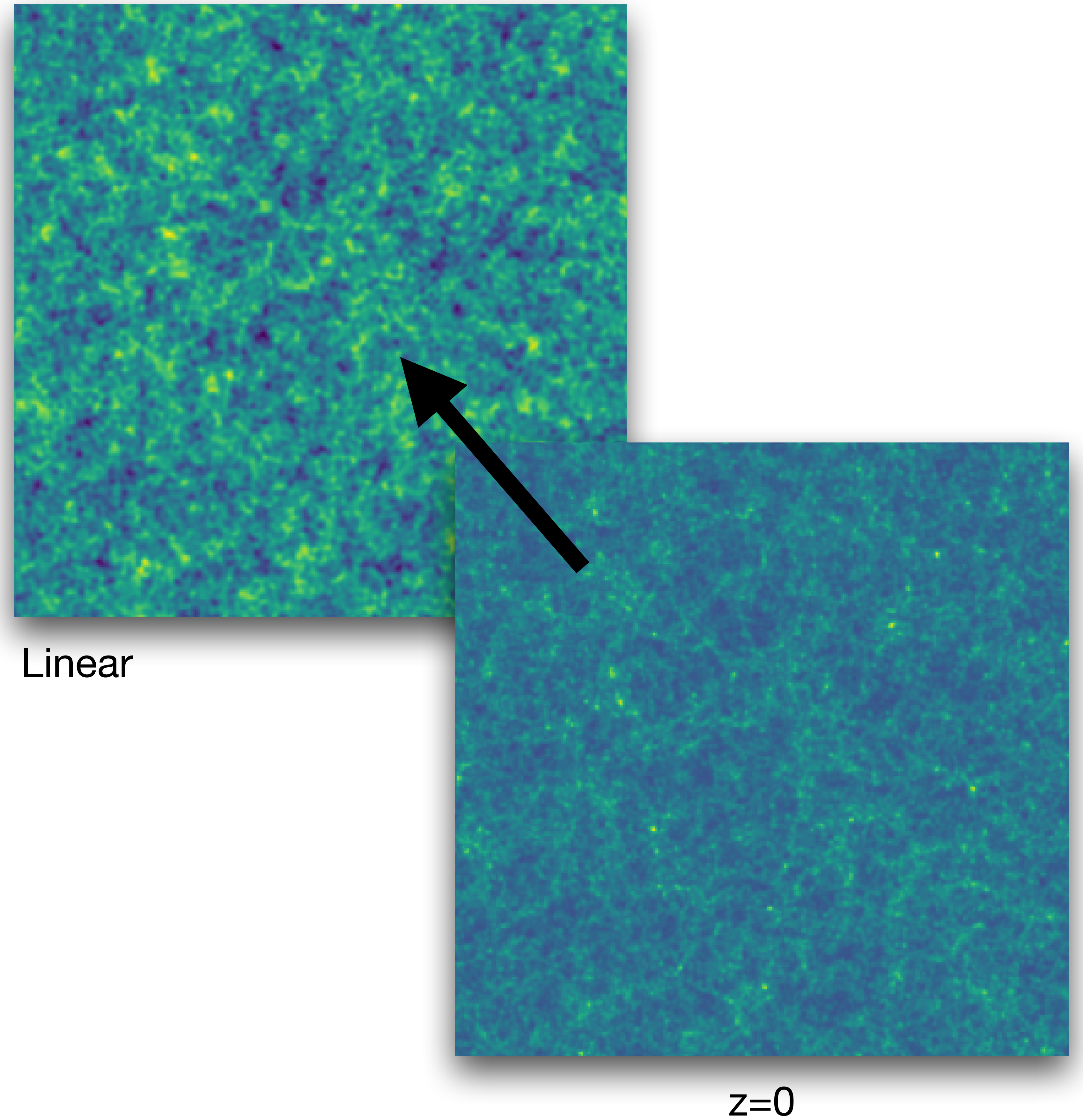
Figure: Fisher forecast on f_{NL} from non-linear matter bispectrum

What now?

- Scale dependent bias helps local pnG, but not equilateral
- Higher-order correlations: expensive, inefficient
- Field contains all the information: how to extract it?

Reconstructing the linear density field

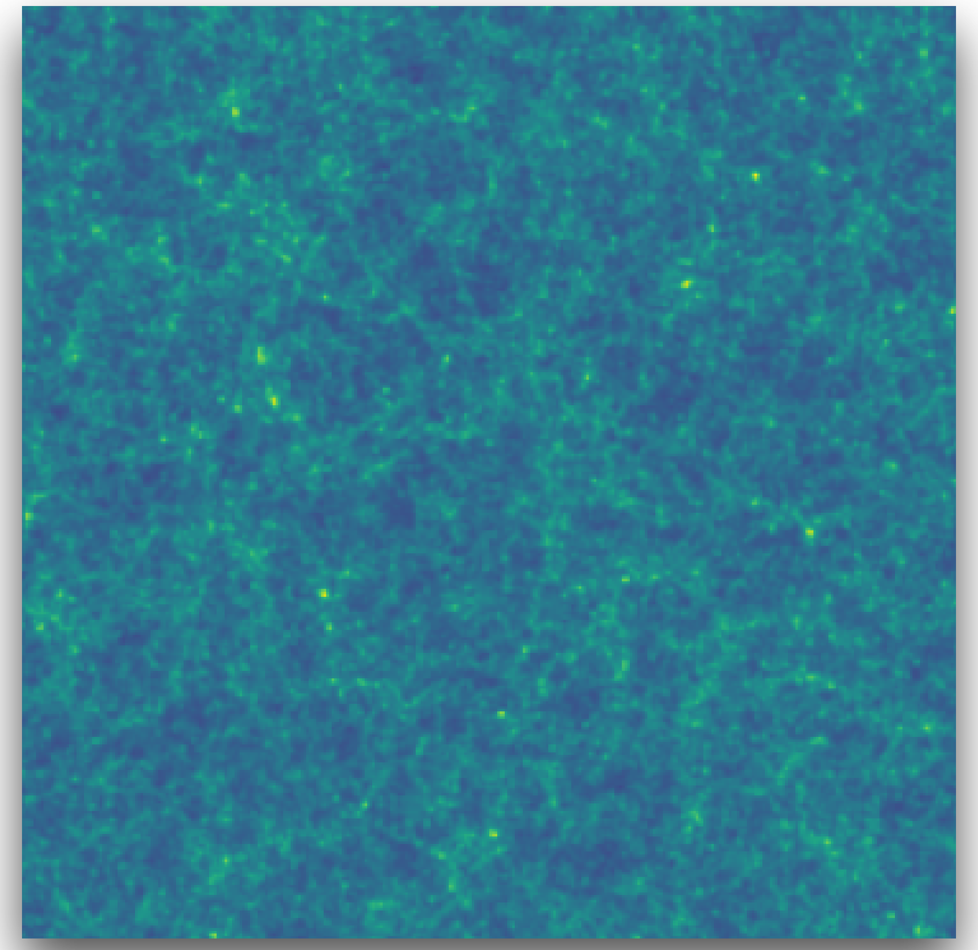
- Linear matter bispectrum contains all information on pnG
- Reconstruction decouples modes
- Moves information back to the bispectrum
- Constrain cosmology from the reconstructed field



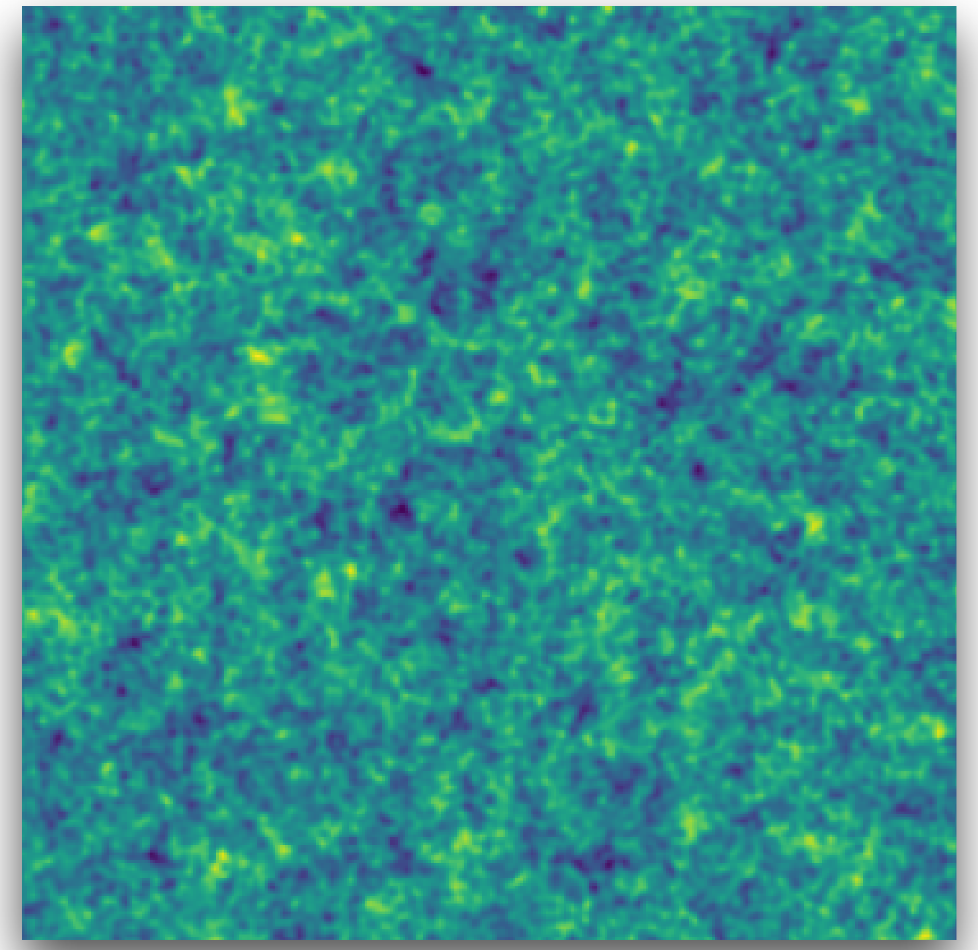
Neural reconstruction

2305.07018 TF & Daan Meerburg

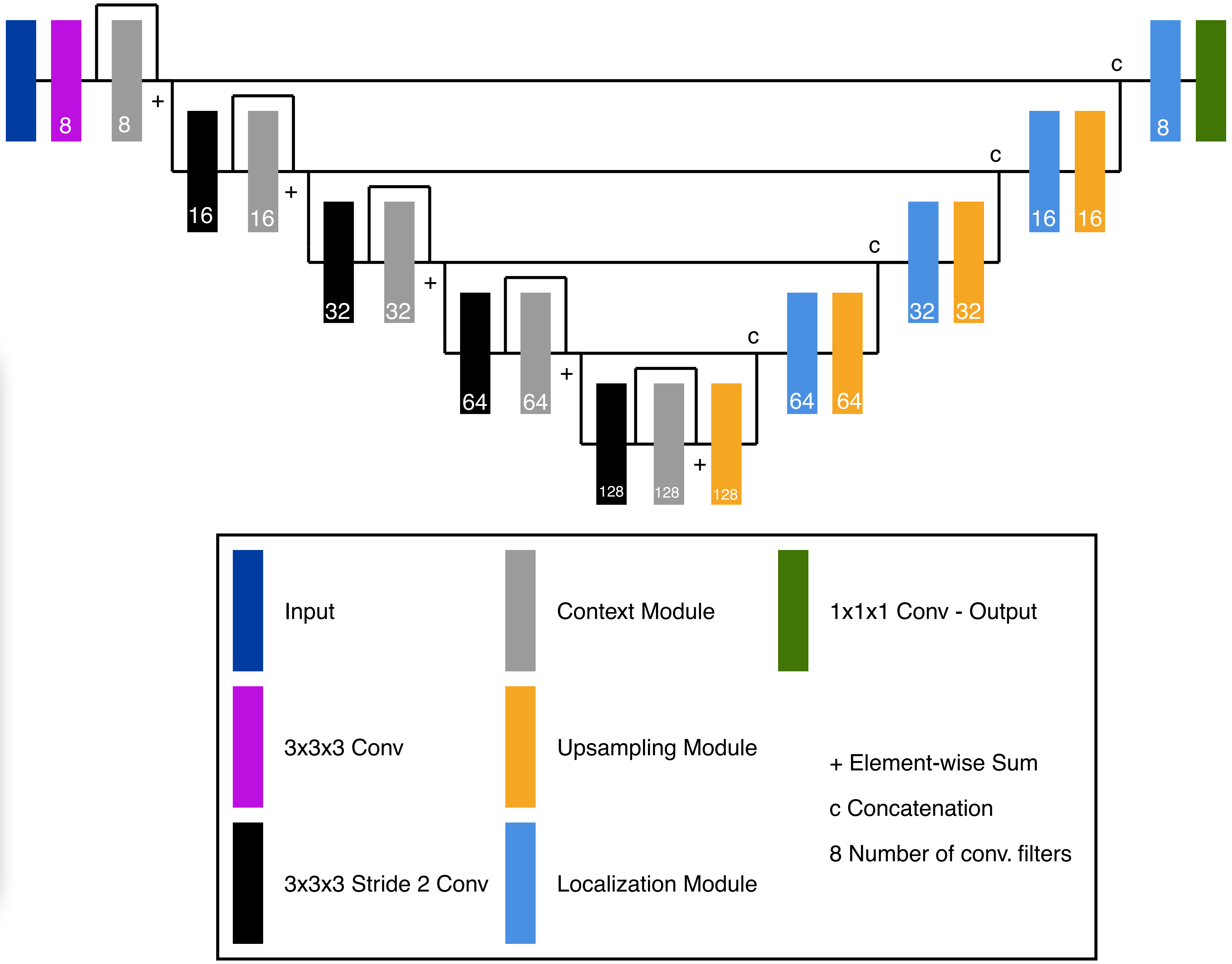
- Image type data: Convolutional Neural Network
- U-Net: effective at different length scales
- Good for many reconstruction problems



z=0 matter density



Linear matter density



Training

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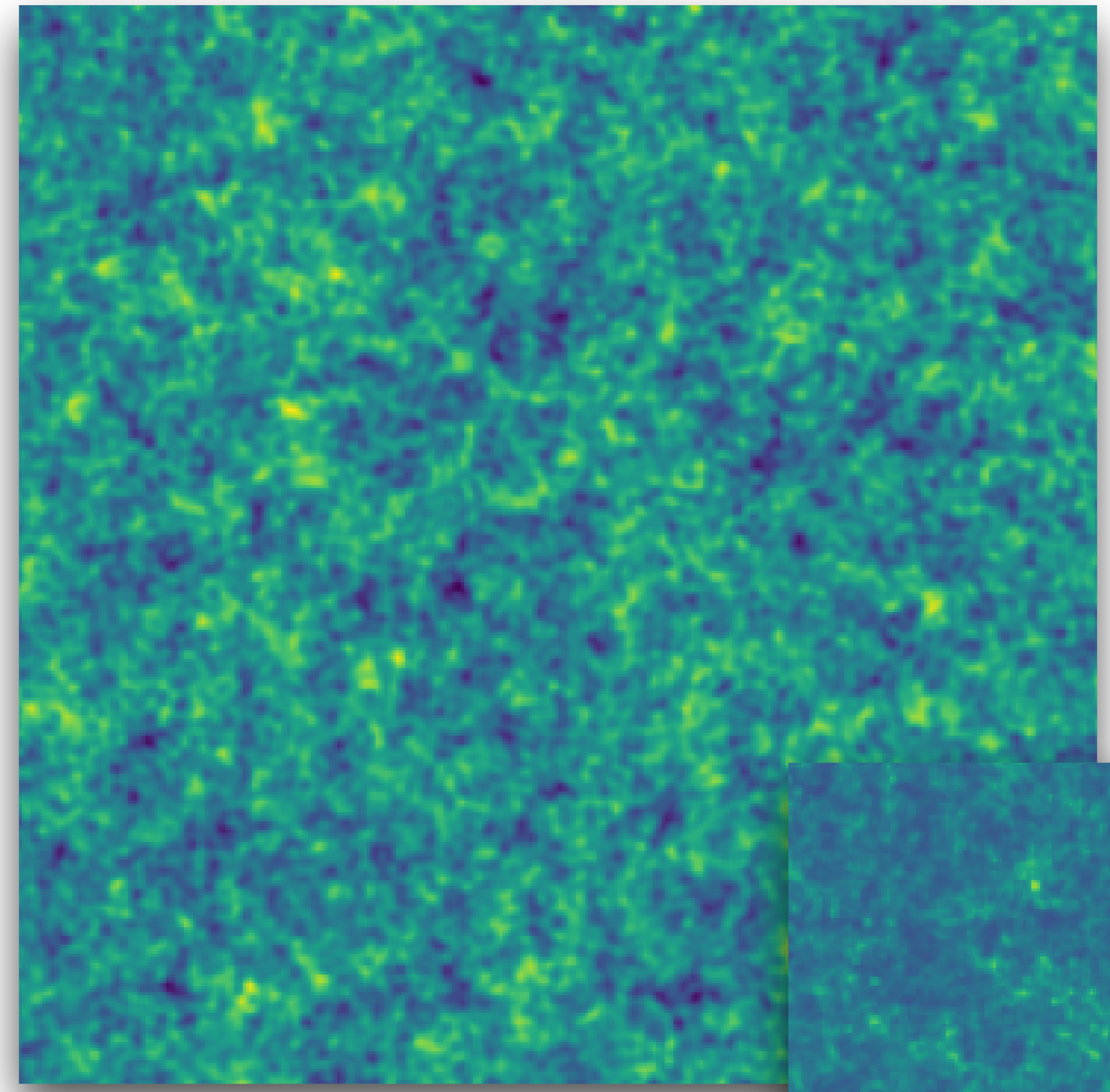
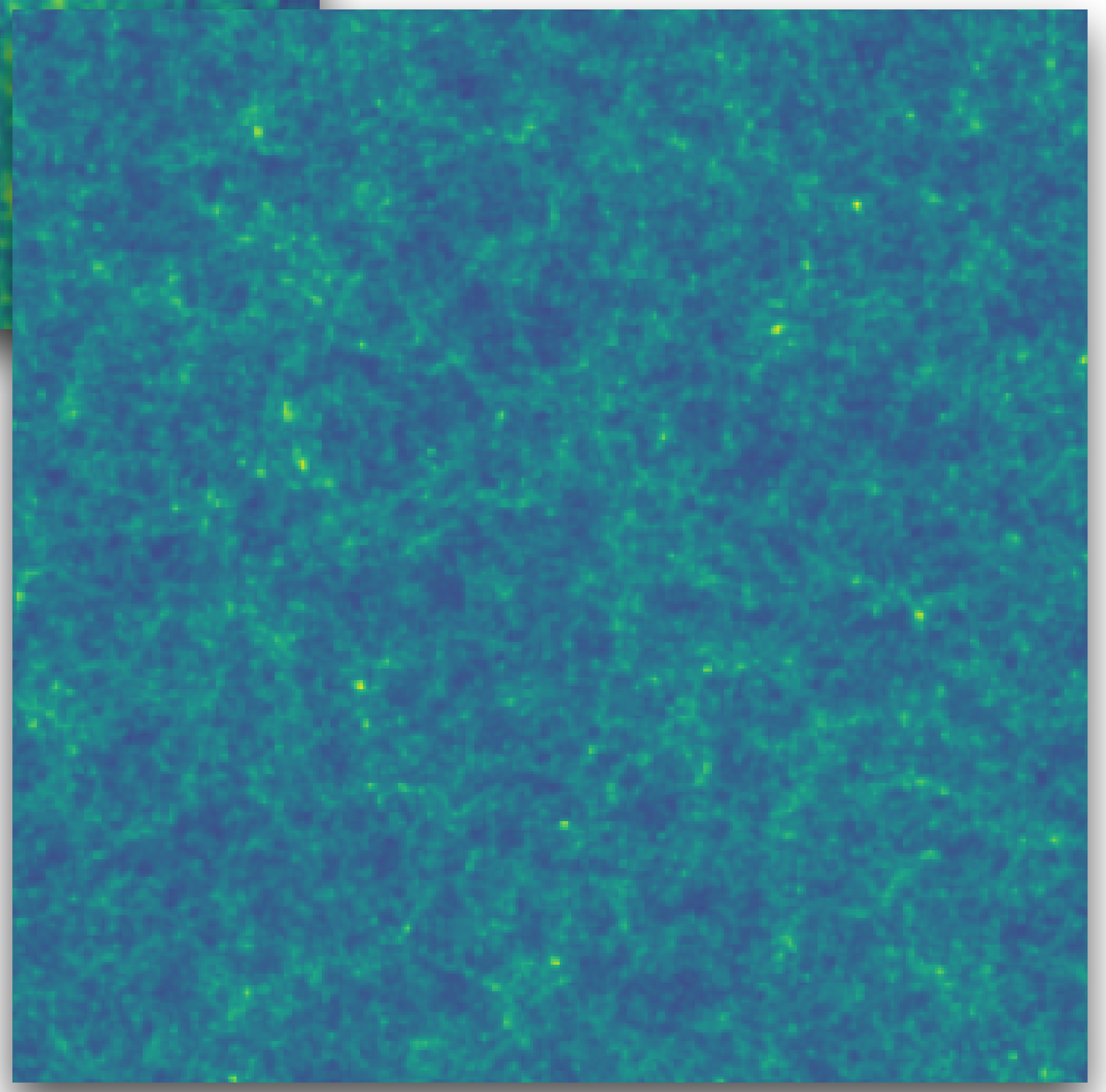
- 48 Quijote N-body z=0 & z=127 density field (256^3) pairs @ fiducial cosmology
- $k_{\max} = 0.8 \text{ h/Mpc}$
- Loss: Pixel MSE
- ~ 4 hours of training (on 4xA100)



z=127



z=0

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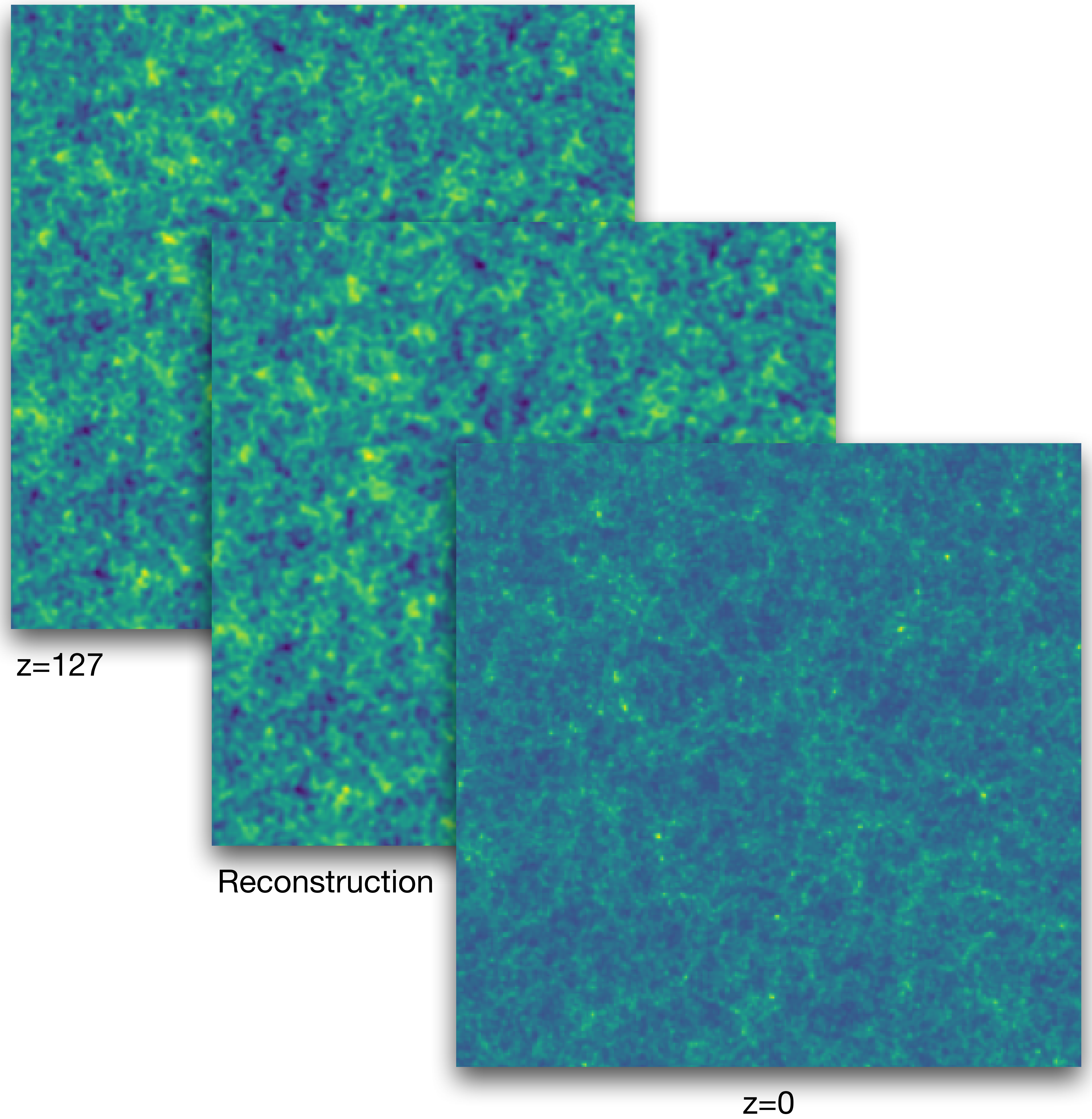

Reconstruction quality

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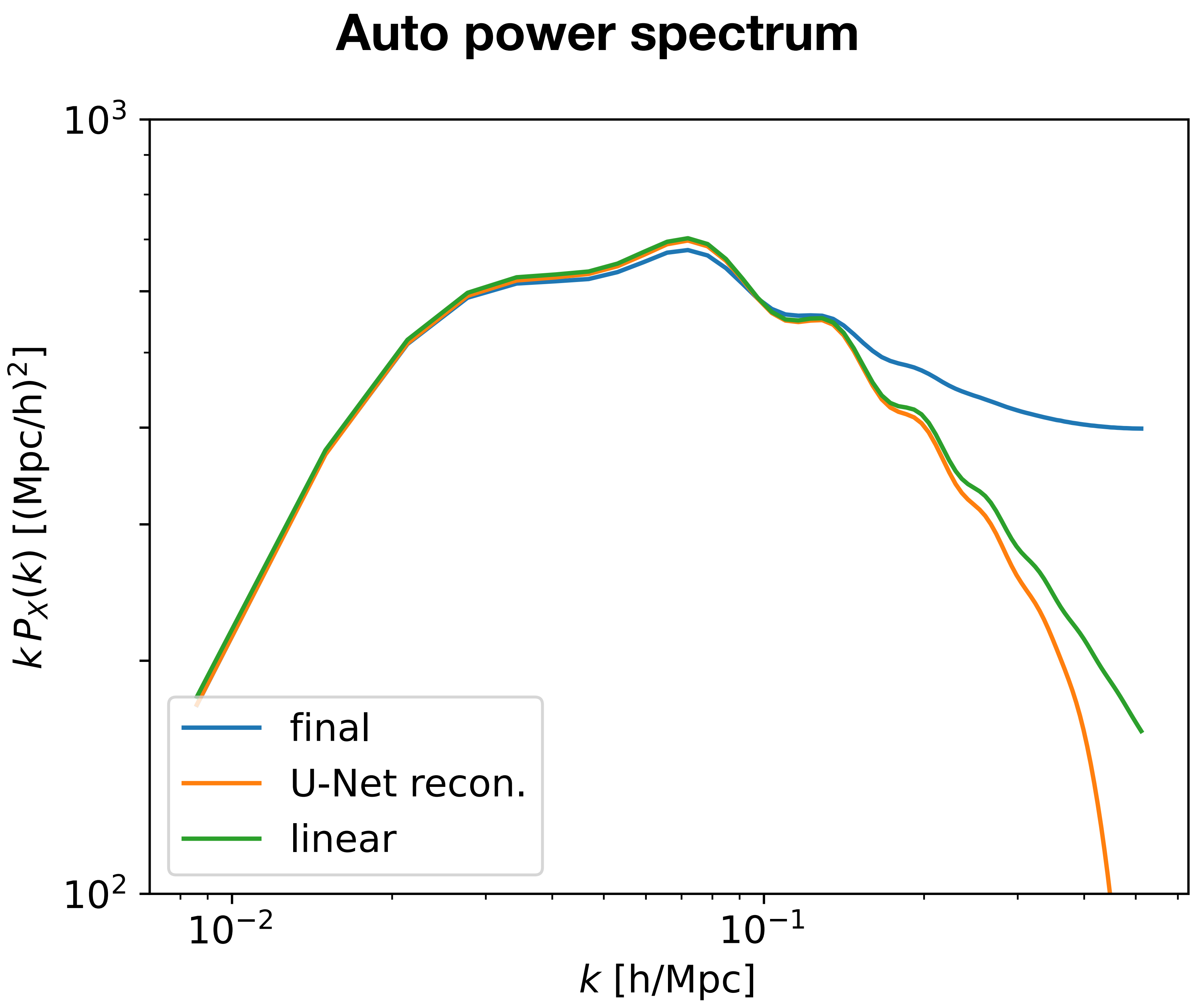

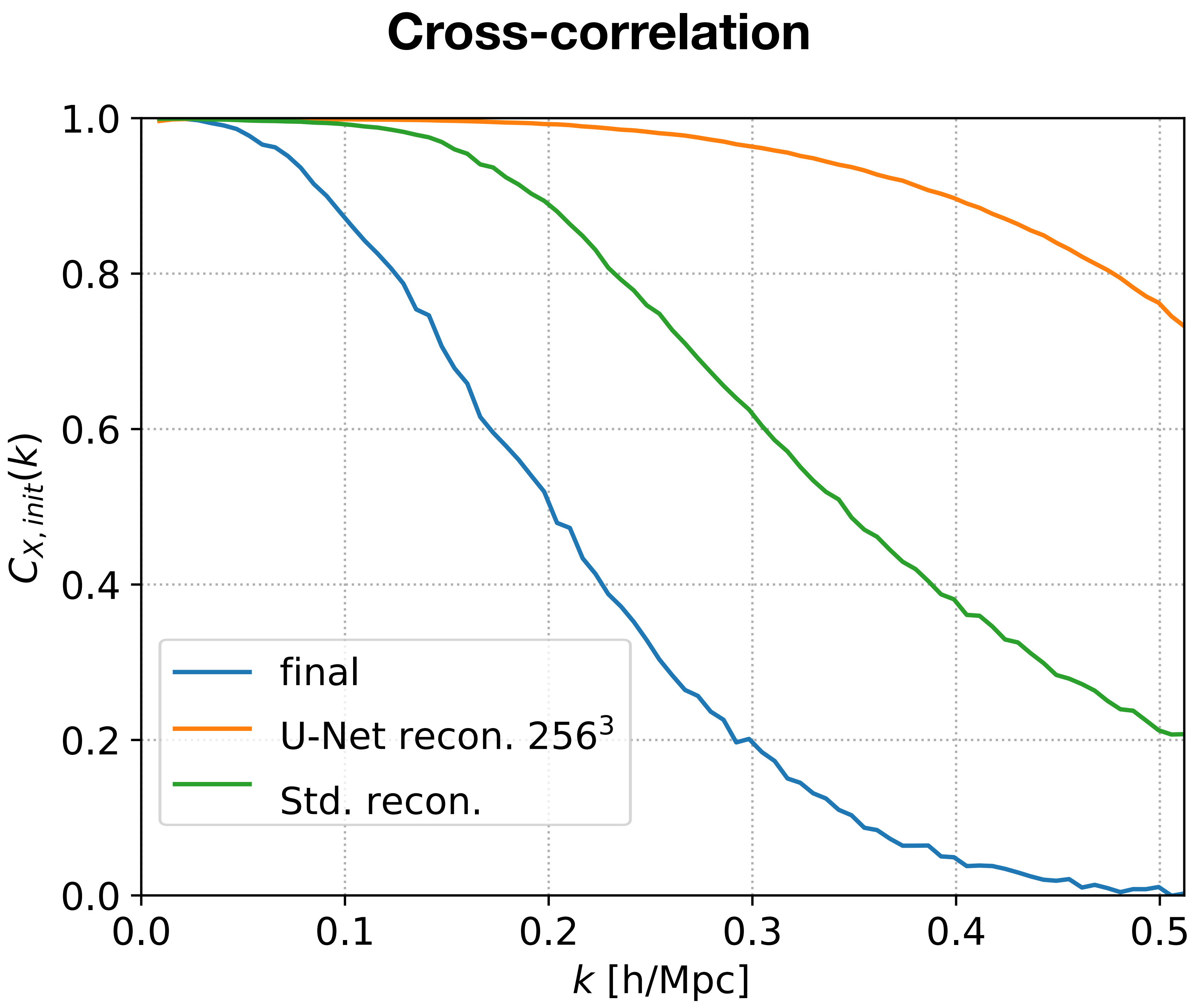

Information content of P+B

$$F_{ab} = \frac{\partial \bar{\boldsymbol{D}}}{\partial \theta_a} \cdot \left(C^{-1}\right) \cdot \frac{\partial \bar{\boldsymbol{D}}}{\partial \theta_b} \qquad\qquad \sigma_a = \sqrt{(F^{-1})_{aa}}$$

- $\boldsymbol{D} = \{P_{\mathrm{pre}}(k),\, B_{\mathrm{pre}}(k),\, P_{\mathrm{post}}(k),\, B_{\mathrm{post}}(k)\}$ up to $k = 0.52$ h/Mpc
- $\theta_a = \{f_{\mathrm{NL}}^{\mathrm{loc}}, f_{\mathrm{NL}}^{\mathrm{eq}}, f_{\mathrm{NL}}^{\mathrm{orth}},\, h,\, n_s,\, \Omega_m,\, \Omega_b,\, \sigma_8\}$

Improving constraints

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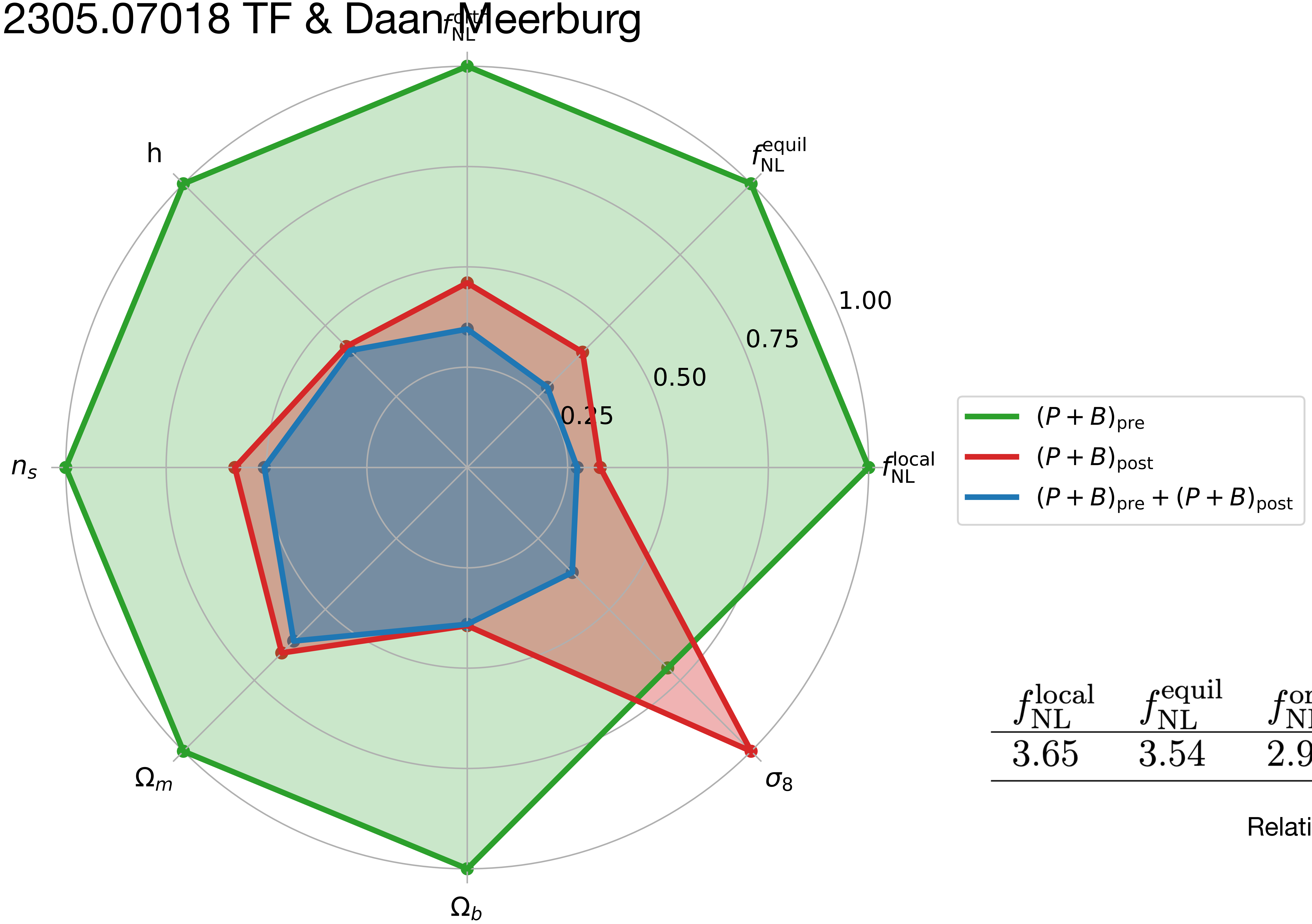

$f_{\rm NL}^{\rm local}$	$f_{\rm NL}^{\rm equil}$	$f_{\rm NL}^{\rm orth}$	h	n_s	Ω_m	Ω_b	σ_8
3.65	3.54	2.90	2.43	1.98	1.64	2.56	1.91

Relative improvement $\sigma_a^{\rm pre}/\sigma_a^{\rm pre+post}$

Halo field

Work to appear by Jelte Bottema, TF & Daan Meerburg

- Halo number density field + redshift-space distortions
- Shot-noise dominated
- Scale dependent bias for $f_{\mathrm{NL}}^{\mathrm{local}}$

Halo field: reconstruction

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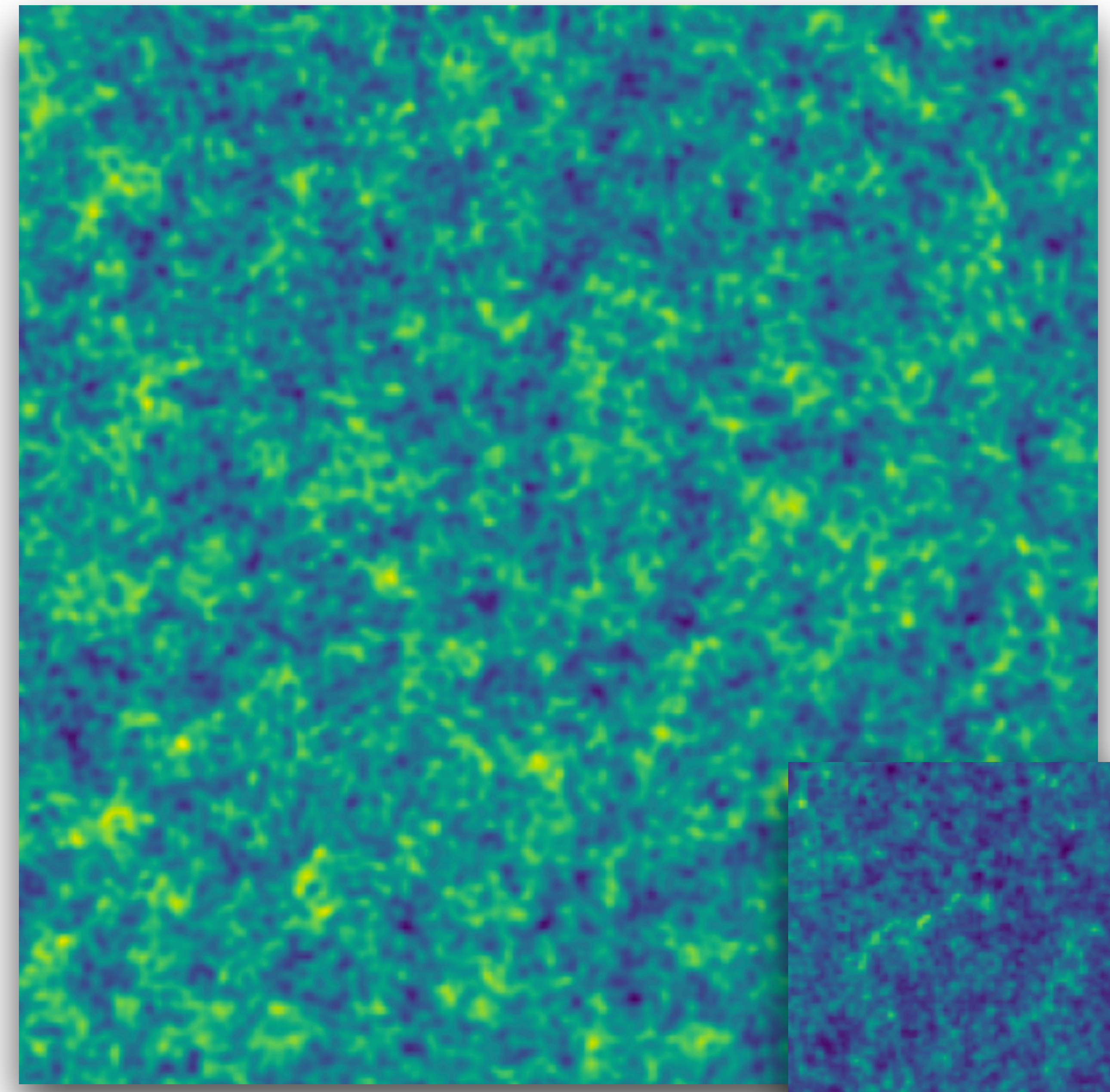
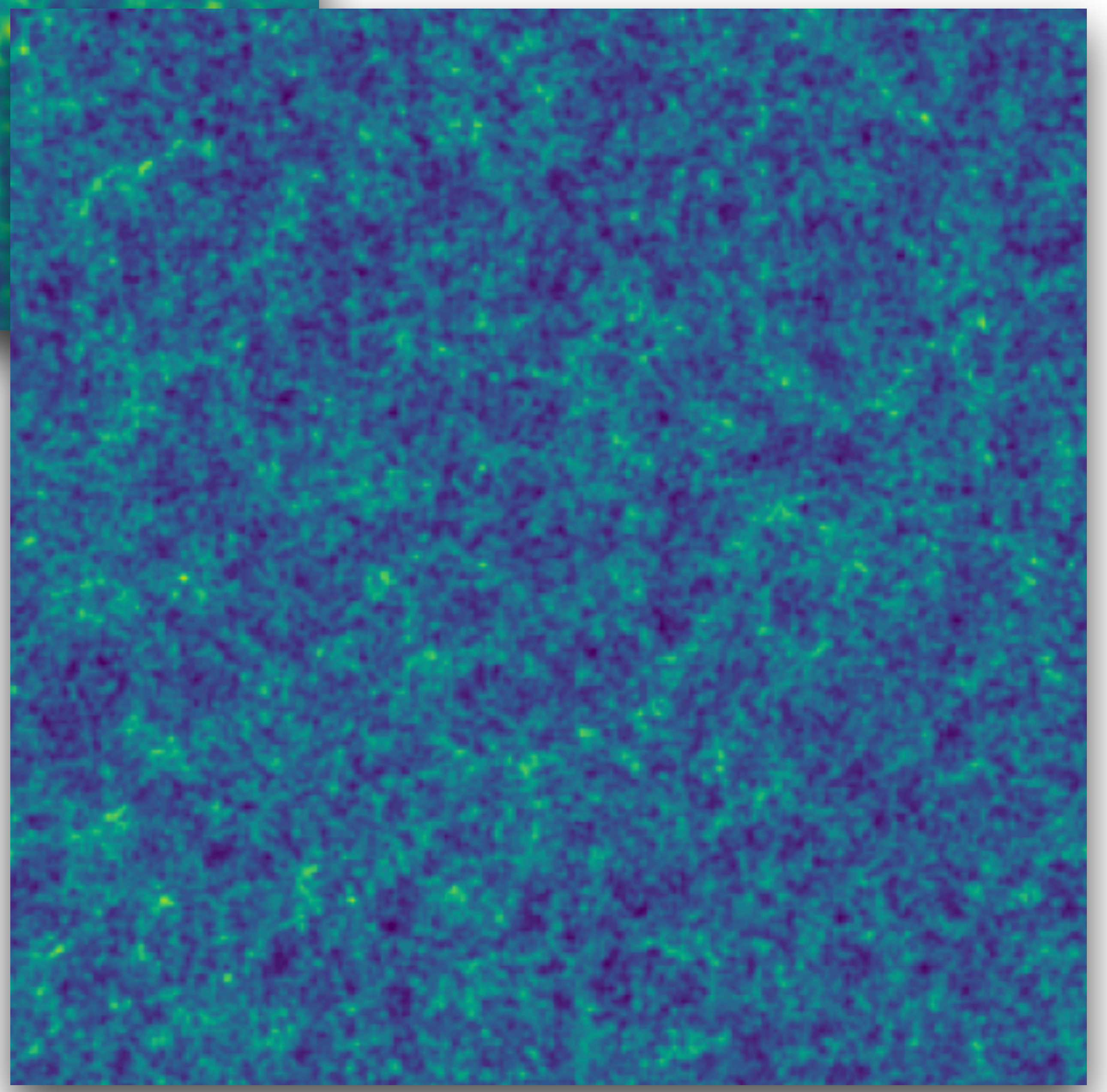


z = 127



z = 0

Halo field: reconstruction

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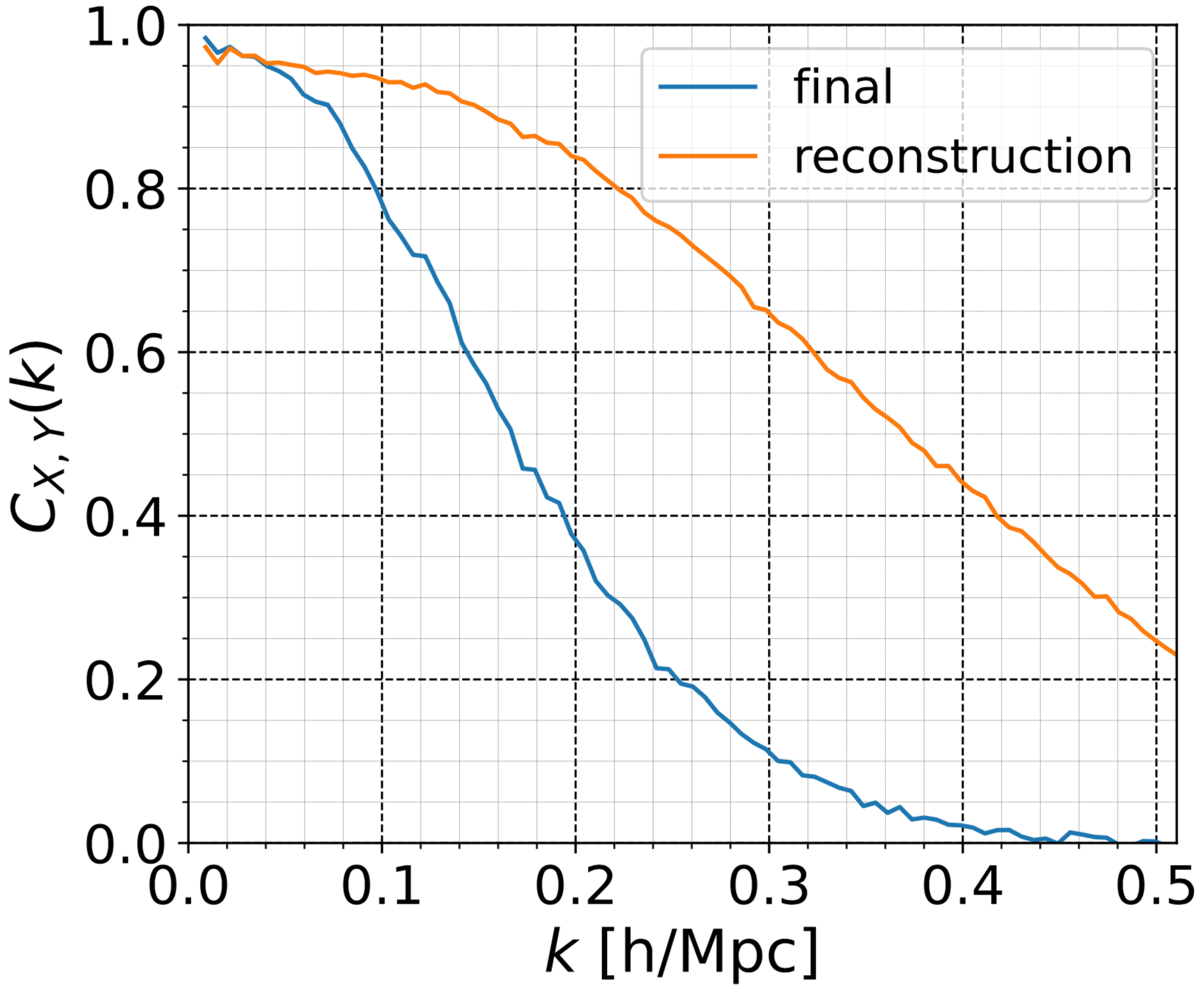

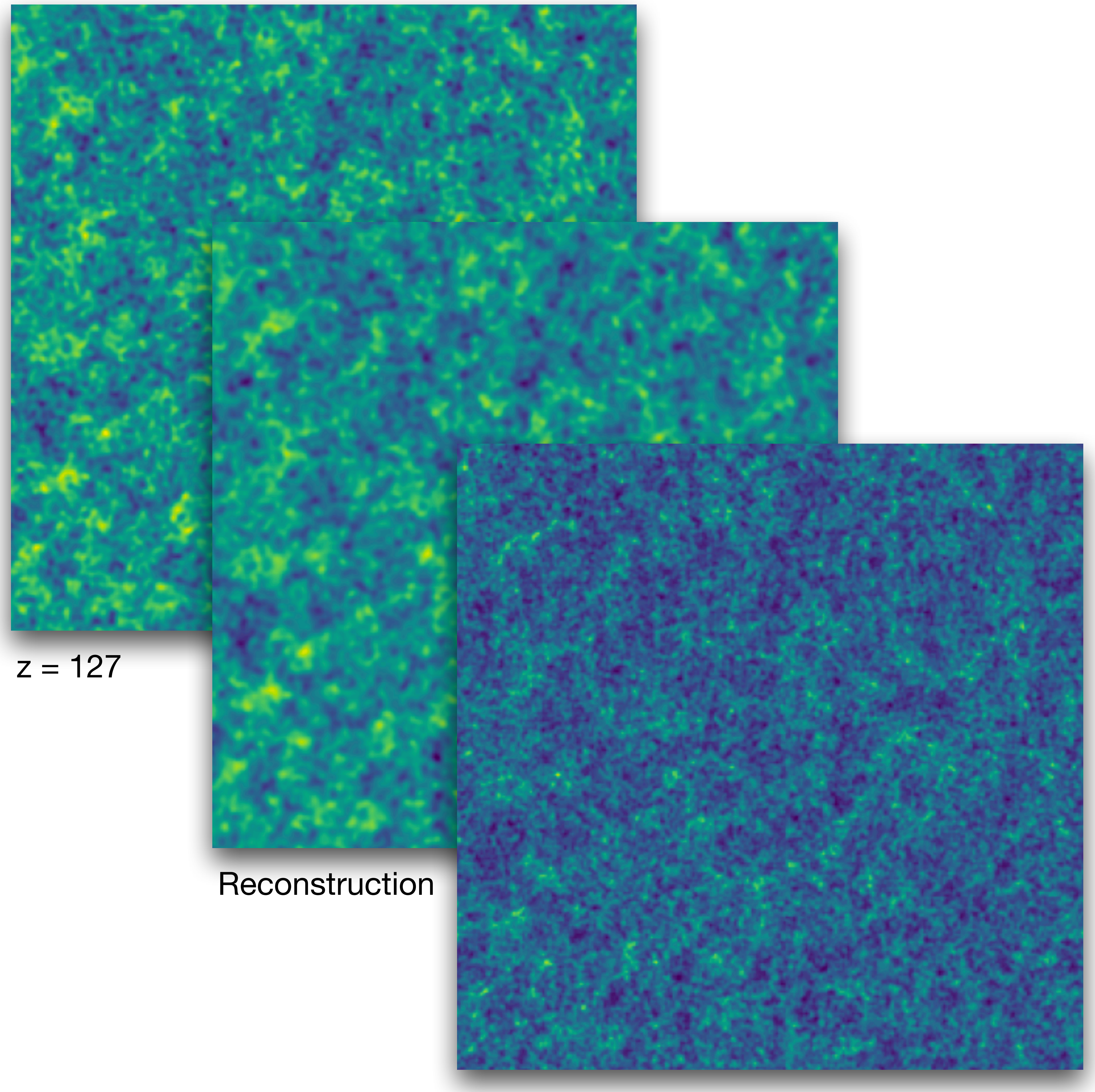

Halo field

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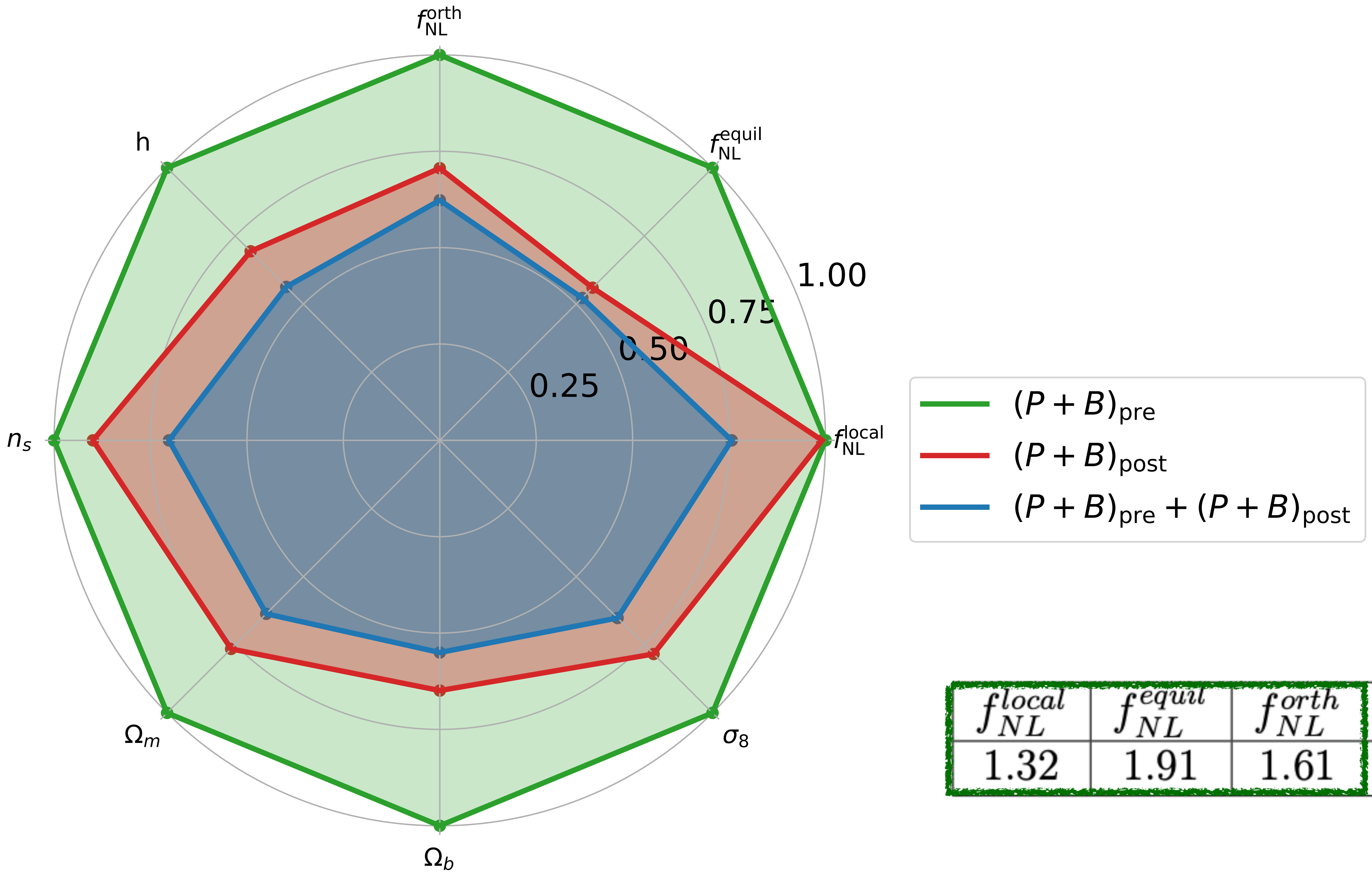

f_{NL}^{local}	f_{NL}^{equil}	f_{NL}^{orth}	h	n_s	Ω_m	Ω_b	σ_8
1.32	1.91	1.61	1.78	1.42	1.57	1.82	1.53

Conclusions & Outlook

- Bispectrum is not optimal for pnG from LSS
- Reconstruction improves information content of the bispectrum
- Improved constraints on cosmological parameters

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- Field level is the way to go
- Differentiable forward modelling
- Bayesian analysis

Thank you!

Questions?

Useful codes for the community

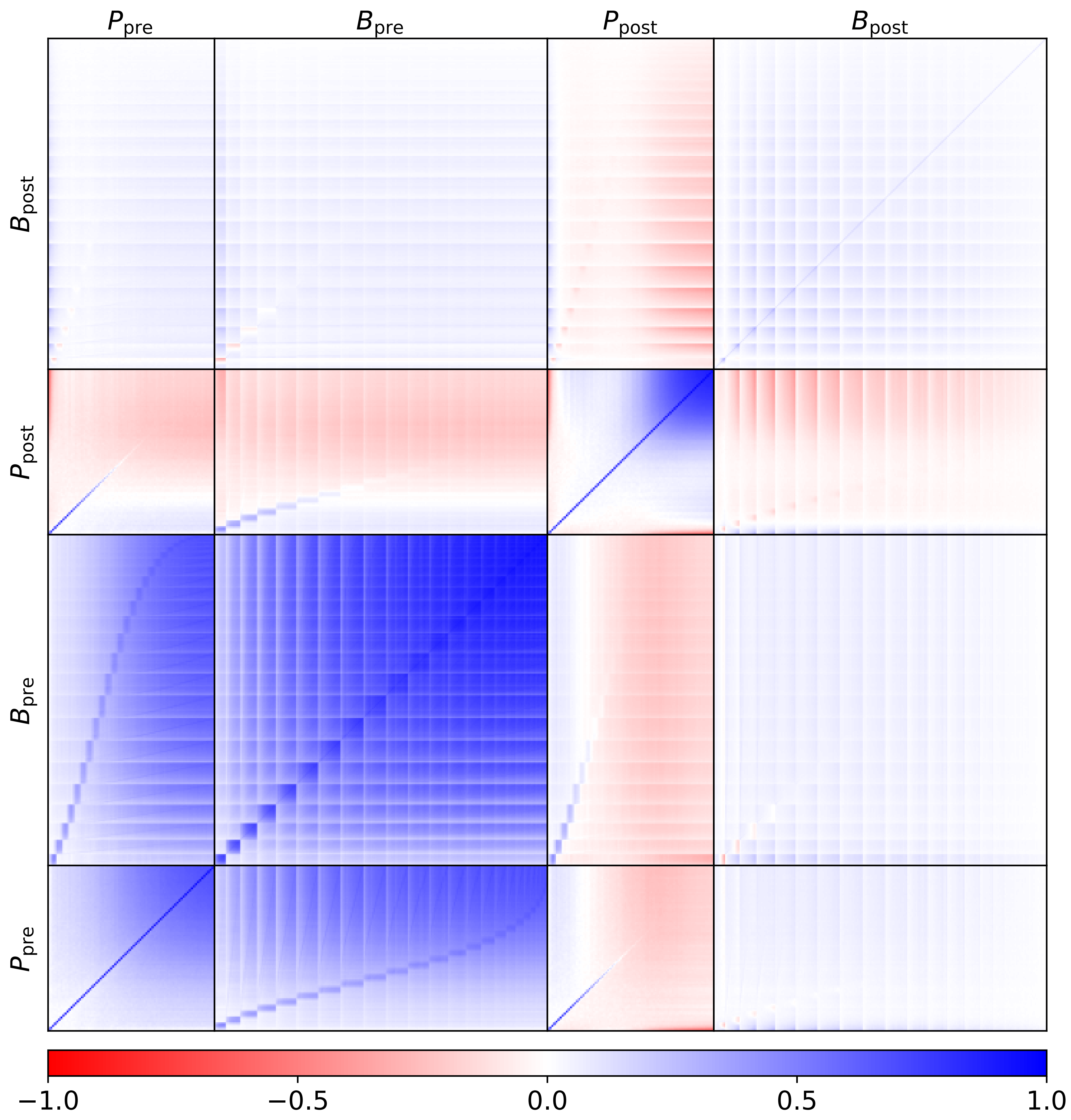
- Fast(est?) FFT bispectrum estimator on GPU (jax): **BFast**
  - https://github.com/tsfloss/BFast
  - ~2300 triangles @ 256^3 grid in 0.5s
  - Differentiable soon

- **PolyBin3D** (Oliver Philcox & TF 2404.07249)
  - Unwindowed & local LOS power spectrum + bispectrum on CPU/GPU
  - https://github.com/oliverphilcox/PolyBin3D

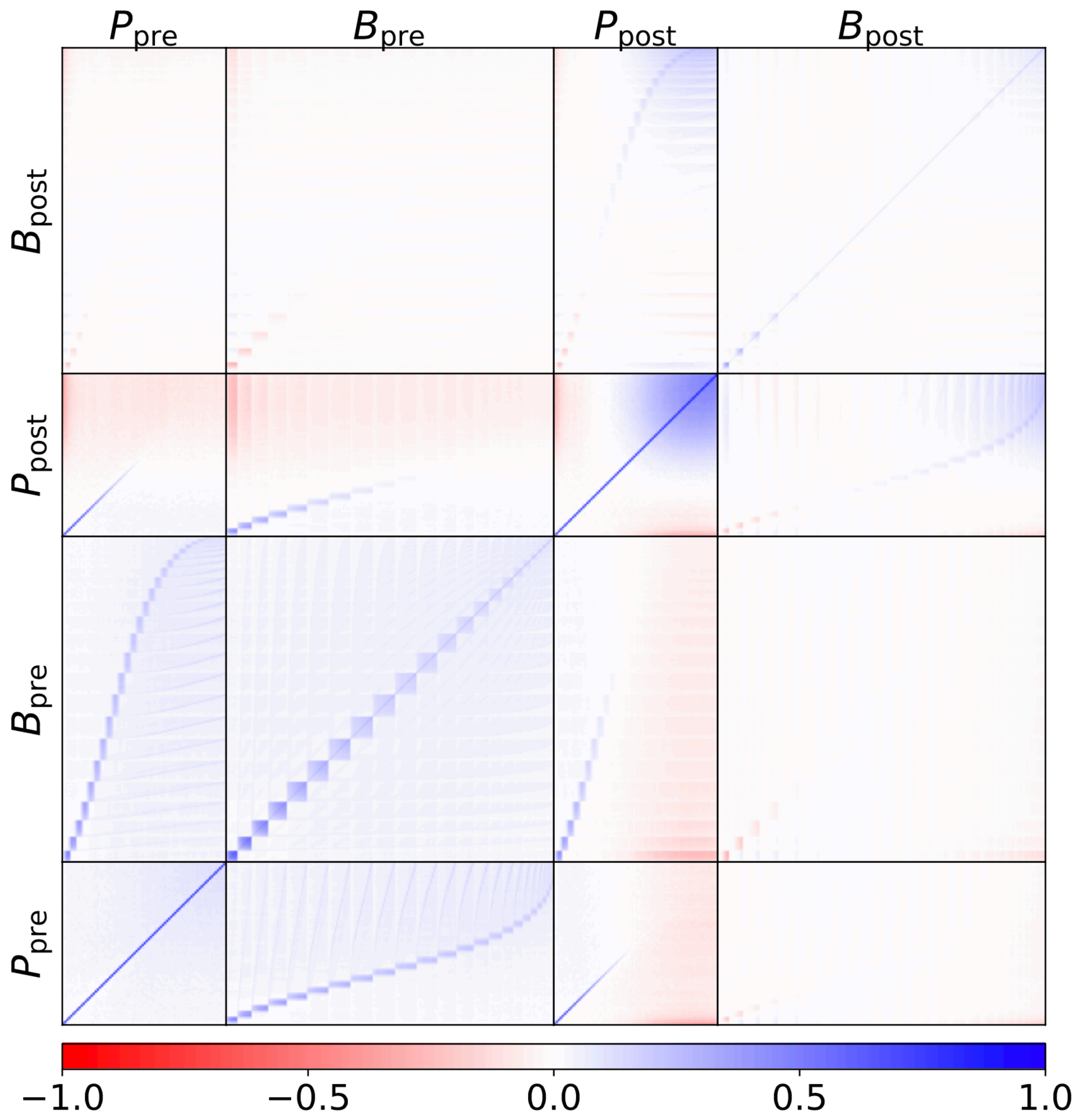
Backup Slides


$\vec{p}_s$
$\vec{k}_s$
$\vec{q}_{1,L}$
$\vec{q}_{2,L}$
$\vec{q}_{1,L}$
triangle$_i$
$\vec{p}_s$
$\vec{k}_s$
$\vec{q}_{2,L}$

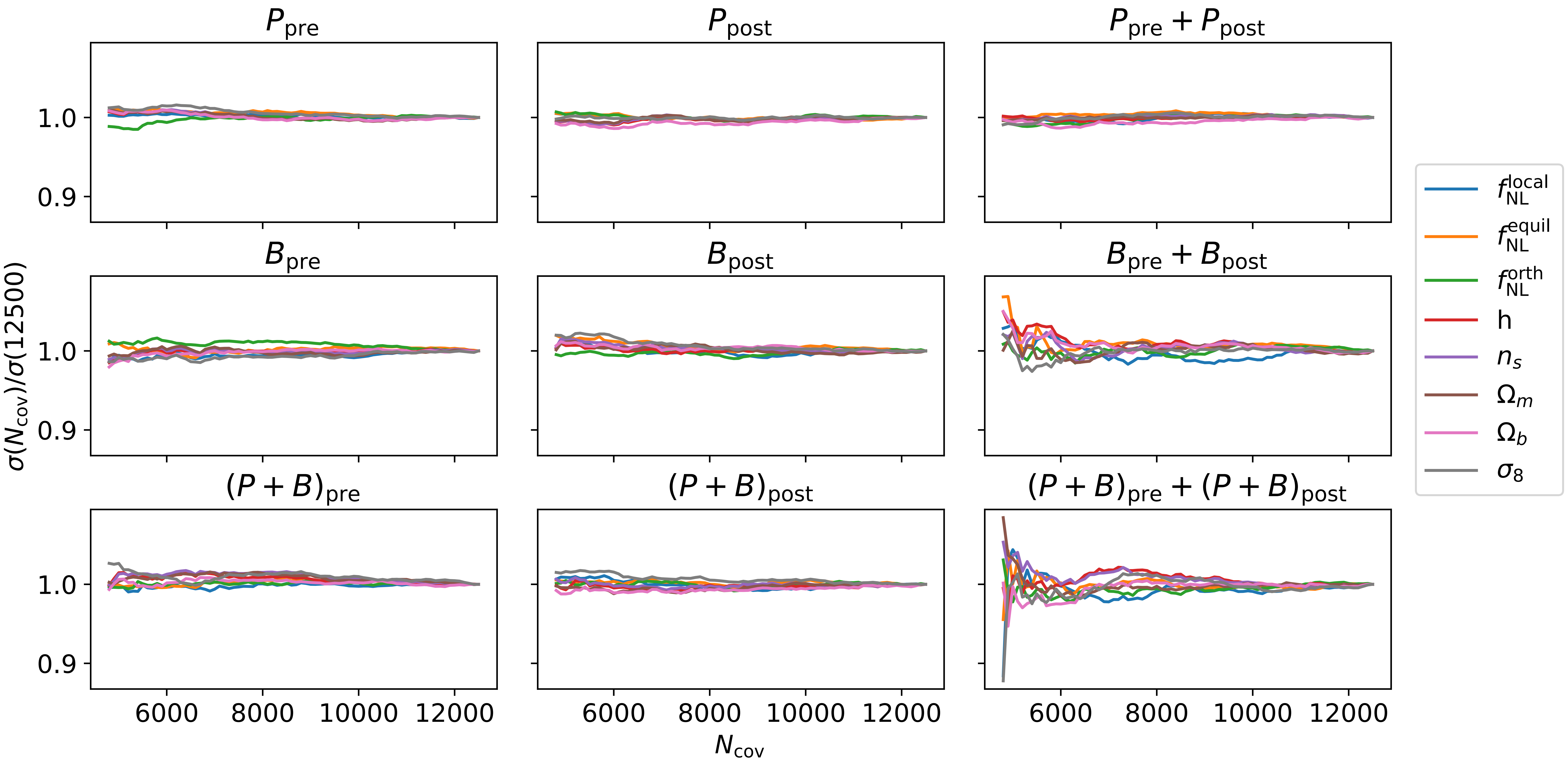
Reduced covariance (matter)



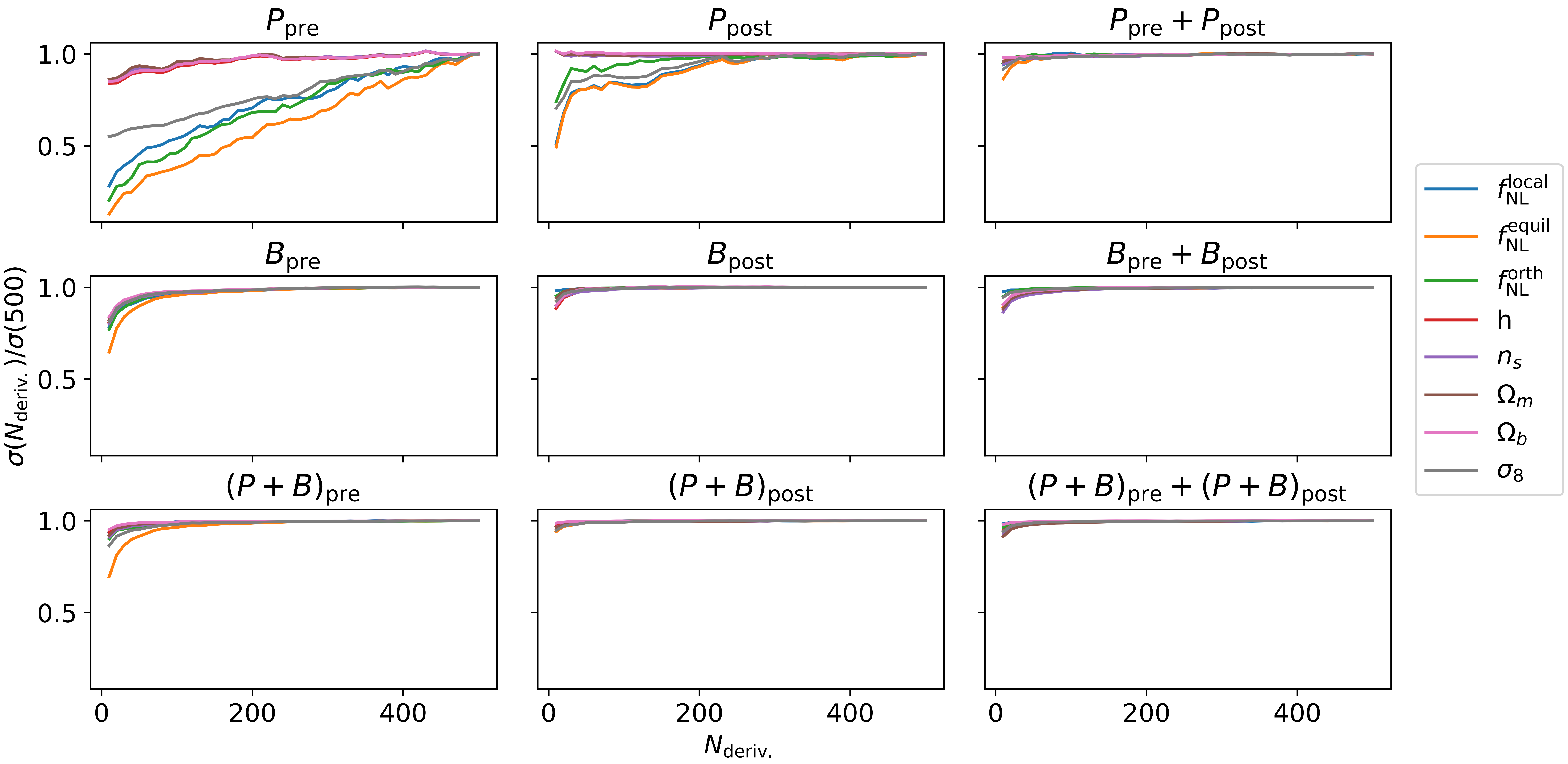
Reduced covariance (halo)



Convergence Tests: covariance

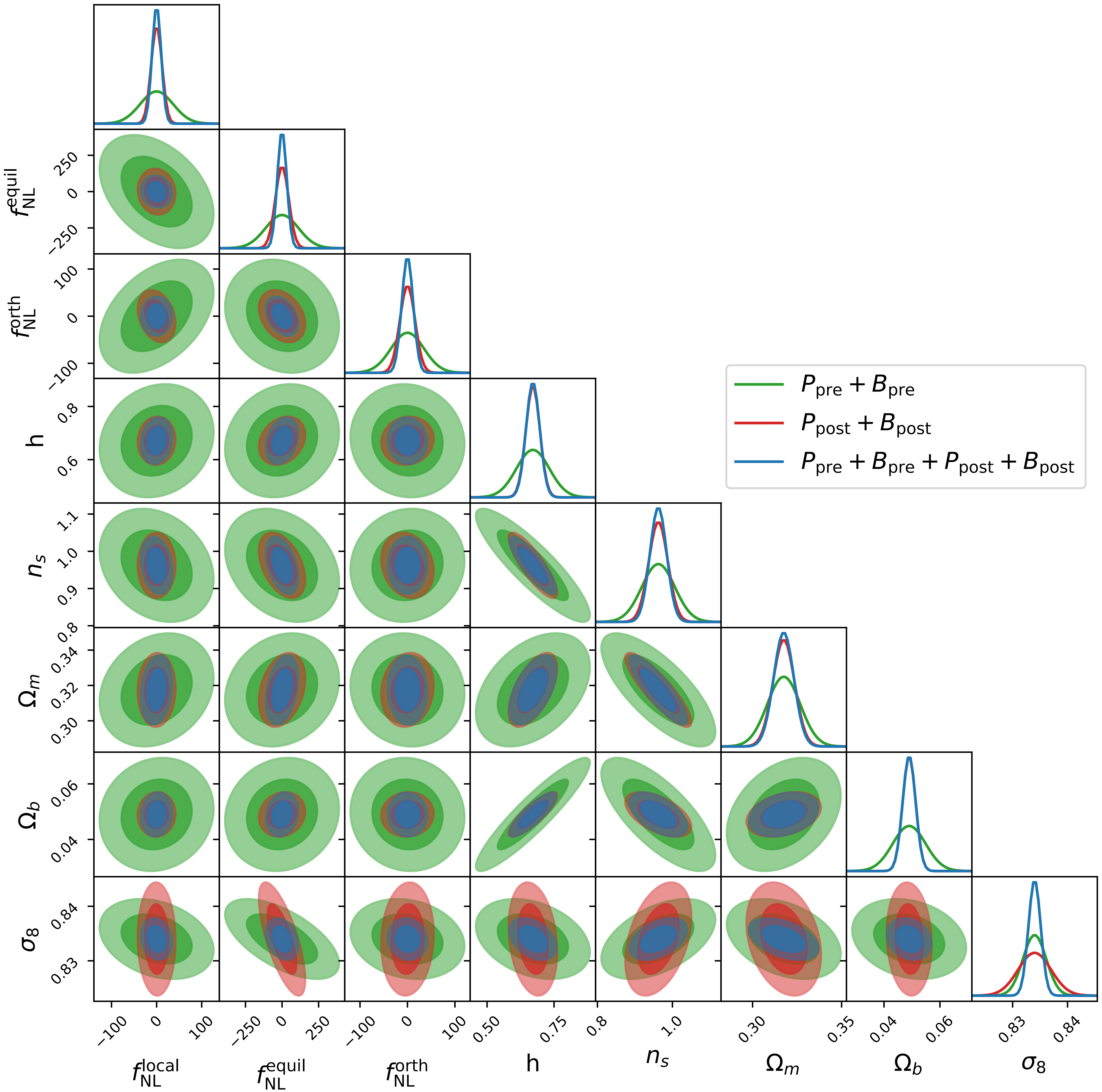


Convergence Tests: derivatives



Contour Plots

Power Spectrum and Bispectrum



Contour Plots

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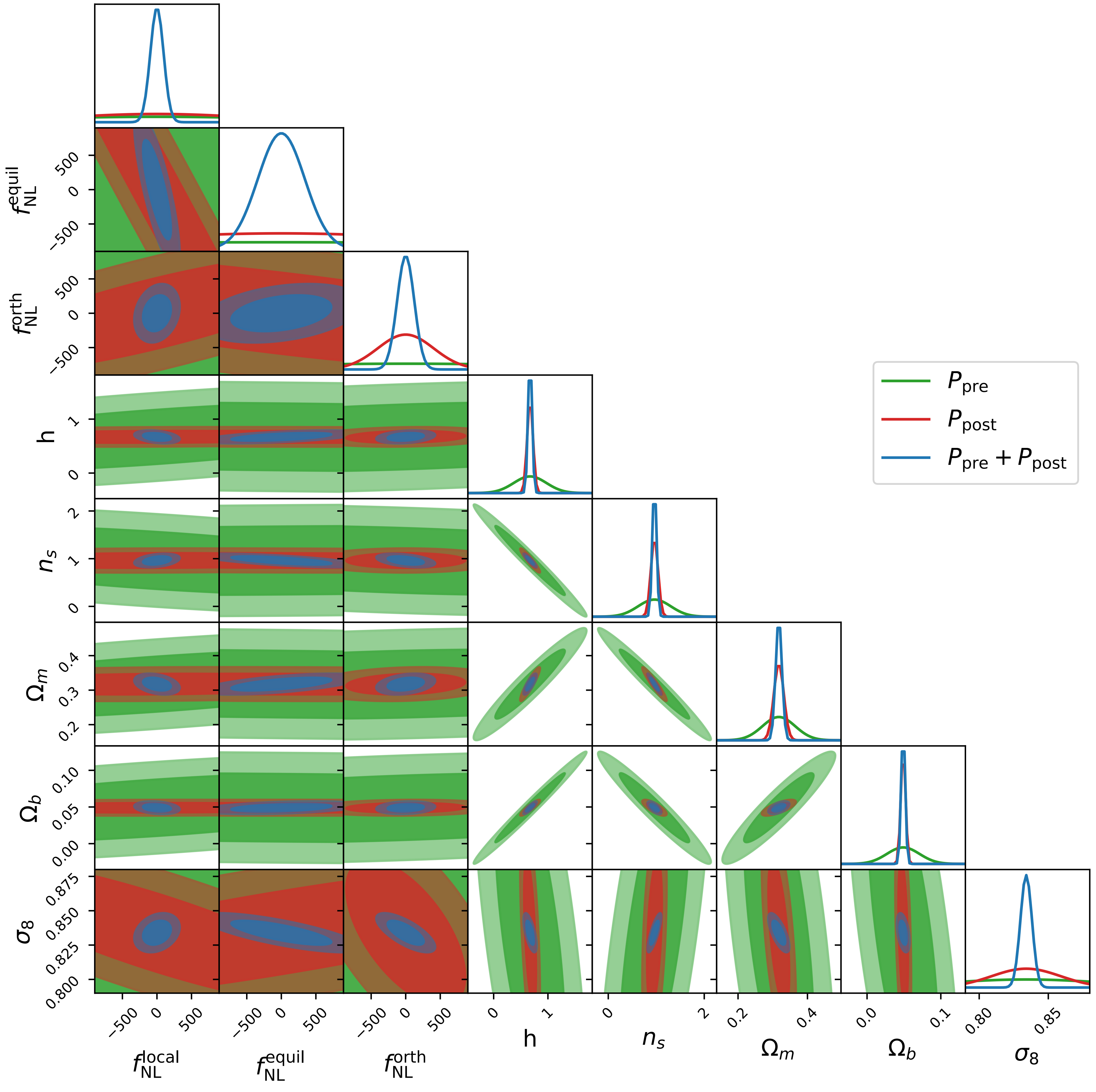

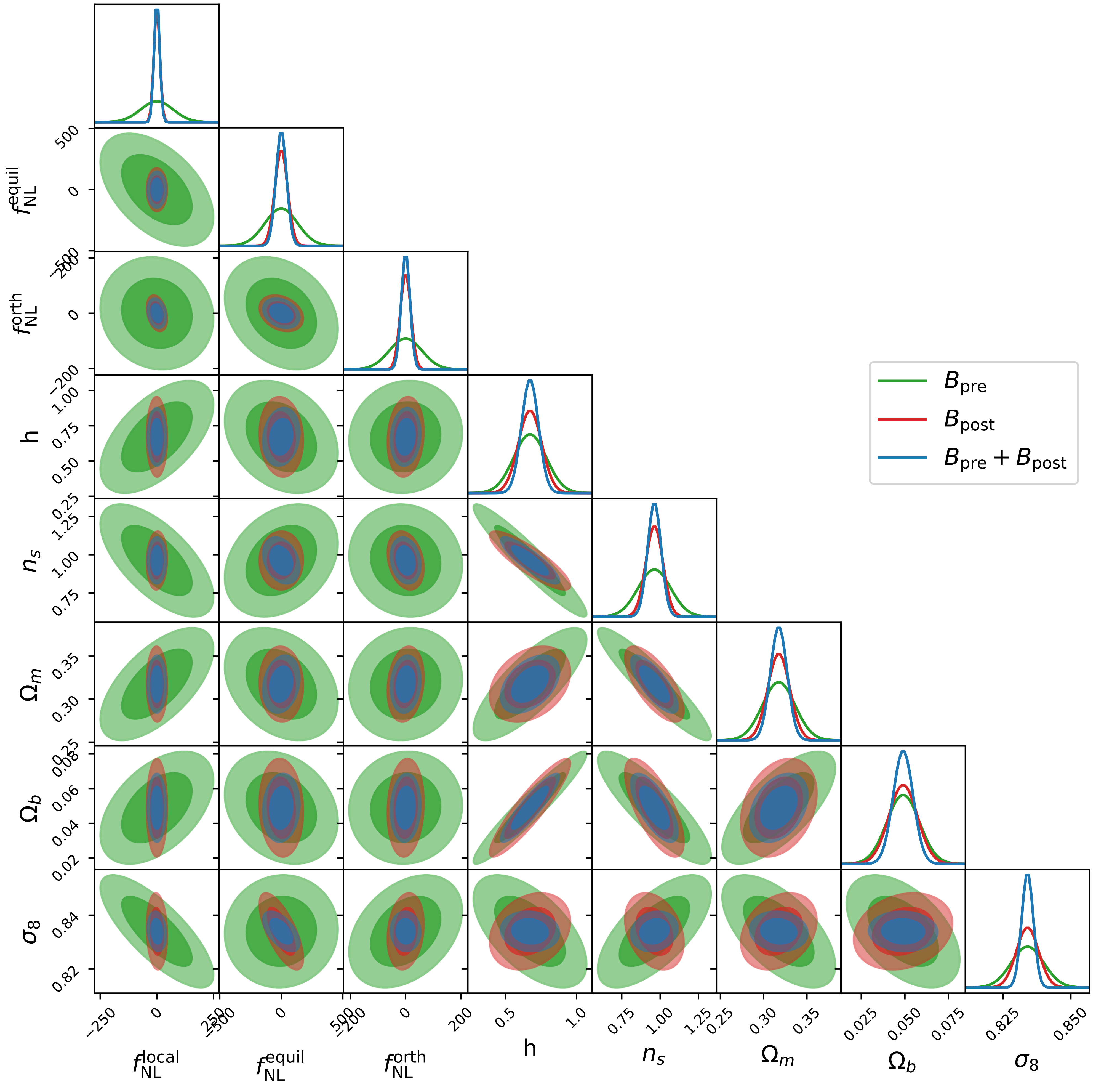

Estimator

$$\hat{\theta}^a - \theta^a_{\rm fid} = \sum_b (F^{-1})_{ab} \frac{\partial \bar{D}}{\partial \theta^b} \cdot C^{-1} \cdot (D_{\rm obs} - \bar{D}_{\rm fid})$$